Compact object mergers as progenitors of short bursts

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Abstract. Compact object mergers are possible progenitors of short burst We analyze properties of compact object mergers using the Star-Track population synthesis code, and find that the double neutron star population is dominated by short lived systems, thus they merge within host galaxies, while black hole neutron star binaries merge outside of the host galaxies.

Key words: star: binaries; gamma rays: bursts

1. INTRODUCTION

Ever since the discovery (Klebesadel, Strong & Olson 1973) of gamma-ray bursts (GRBs) the main problem faced by researchers was to identify the physical mechanism behind these phenomena and to place them somewhere within the realm of standard astrophysics. The discovery of afterglows (Costa et al. 1997) lead to great progress in the field. It allowed to identify GRB host galaxies, and to study their properties. GRB afterglows were localized within host galaxies. Long GRBs take place inside small star forming galaxies.

Coalescences of compact object binaries have been considered as a possible mechanism of GRBs. Several types of such mergers were considered - see Fryer, Woosley & Hartmann (1999). The main problem is that the timescale of the merger is relatively short and it is difficult to explain long bursts, yet it is still possible that the progenitors of short bursts are compact object mergers.

These discoveries were followed by several studies (Bloom, Sigurdsson & Pols 1997; Bulik, Belczynski & Zbijewski 1997) using the population synthesis approach to calculate offsets for simulated populations of possible GRB progenitors, with conclusion that most double neutron star binaries merge outside host galaxies.

Here we report the results of the careful examination of properties of compact object binaries with the StarTrack population synthesis code (Belczynski, Kalogera & Bulik 2002), which singificantly changes the conclusions reported above.

2. PROPERTIES OF COMPACT OBJECT BINARIES

A novel feature of the StarTrack code (Belczynski, Kalogera & Bulik 2002) was to include the evolution of He stars. Within the code helium stars with the mass under $4.5\,M_{\odot}$ develop convective envelopes. This leads to a possibility of initiating common envelope (CE) episodes by He stars in close binaries.

We have found that one can identify three different types of evolutionary paths leading to formation of double neutron star (NSNS) binaries (Belczynski, Bulik & Kalogera 2002). Group I contains systems which involved a double CE phase between tow helium stars which later underwent supernova explosions. Group II consist of systems which underwent a CE with a He star donor in a binary with a NS. Group III are the remaining, classical systems for which no CE phase with an He star took place. The systems of Group II dominate the population of NSNS binaries, they constitute nearly 90% of the entire population of such objects. However these binaries as well as the ones of Group I are very short lived. The additional CE phase tightens up these systems which decreases significantly their lifetimes as compact object binaries. The typical lifetimes due to gravitational wave emission of these binaries is $\approx 1\,\mathrm{Myr}$. The nuclear lifetimes of their progenitors is about ten times longer. On the other hand black hole neutron star (BHNS) binaries cannot undergo this additional CE phase because the massive He star do not have convective envelopes. Therefore the BHNS binaries are much more long lived. The NSNS binaries of Group III are also long lived, the typical lifetimes of BHNS and NSNS binaries of Group III stretches from a Gyr to the Hubble time. We present the distribution of lifetimes of BHNS and NSNS binaries from the formation of two stars on ZAMS to the merger due to gravitational wave emission in Fig-
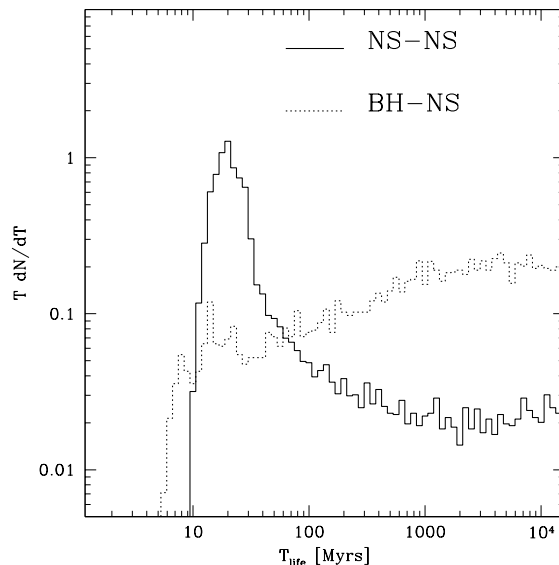
Fig. 1. The distributions of the lifetimes of NS-NS binaries ans BH-NS binaries.

ure 1. Since the population of NSNS binaries is dominated by the Group II systems the typical lifetime of such systems stretches from 10 to 50 Myrs.

Given the lifetimes and the velocities attained due to supernova kicks by the compact object binaries one can calculate the distributions of their merger sites around galaxies. We have found that the NSNS binaries merger predominantly within the host galaxies, contrary to the results of previous studies (Belczynski, Bulik & Rudak 2002). This is due to the fact that although the spatial velocities of the NSNS binaries are of the order of up to few hundred $km\,s^{-1}$, their lifetimes are short and they do not have the time to leave the host galaxies. The NSNS binaries of Group III manage to leave the host galaxies and merge outside of them. BHNS binaries leave the host galaxies: although their spatial velocities are smaller their lifetimes are much longer.

3. CONCLUSIONS

We have reviewed the properties of possible progenitors of short GRBs: the coalescences of compact object binaries. We find that the

Table 1. Properties of compact object binary mergers.

	NSNS	BHNS
Merger sites	inside galaxies	outside galaxies
Trace star formation	Yes	No
Luminosity function	Narrow	Wide

properties of the NSNS and BHNS binaries are significantly different. The lifetimes of a majority of NSNS binaries are much shorter then the lifetimes of BHNS binaries. We find that the distribution of merger sites of these two types of binaries are different: NSNS binaries merge inside host galaxies, while the BHNS binaries merge outside of them. The difference in the lifetimes of these two types of binaries implies also different redshift distributions of such mergers. The NSNS binary mergers shall trace the star formation rate history, while the BHNS mergers shall not because of their long lifetimes. Finally, the luminosity function, or rather the internal pool of energy in the burst should be much narrower for the NSNS mergers than for the BHNS mergers. This is due to the fact that the mass range of neutron star is rather narrow, while the masses of black holes of stellar origin may reach up to $15 - 20\,M_\odot$ for population I stars, and could be much higher for the black holes originating from lower metallicity population II and earlier stars. The properties of NSNS and BHNS mergers are summarized in Table 1.

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